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GB 1462159
US 4000936 A
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(54) **Reinforced Optical Fiber Conductor and Optical Fiber Cable Incorporating such Conductors**

(57) A reinforced insulated and buffered optical fiber conductor (20) comprises an optic fibre (10) coated with a compliant jacket (12) of insulating material, further covered by a layer of fine metallic wires (16) to form a cylindrical shield around the optical conductors and which is, in turn, covered with a jacket (18) of compliant insulating material of substantial thickness relative to said optical conductor. These conductors (20) may be essentially evenly spaced and wound at a small angle such as fifteen degrees around a centrally disposed monofilament plastics rod (22) with a plurality of conventional metallic conductors (24) wrapped on said rod between said optical conductors. These conductors are then covered and secured in places with an extruded elastomer polyurethane jacket (26). A woven bedding braid (28) covers the polyurethane jacket (26), and it is covered with two layers (30, 32) of steel armor wires, each of which includes a plurality of fine parallel wires laid at a shallow angle with respect to said rod, these layers being laid in opposite directions to provide torque balancing for the cable as it is loaded in tension.

FIG. 1

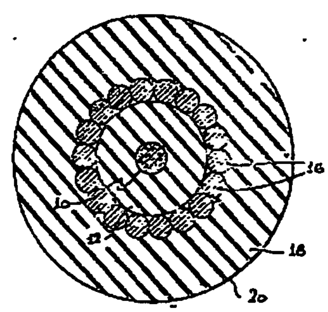
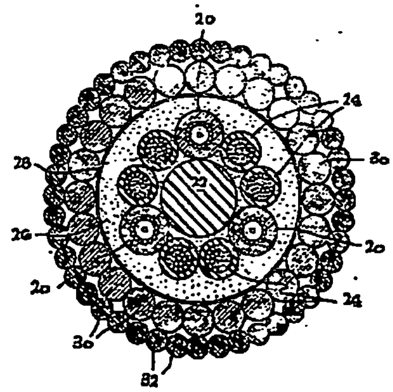


FIG. 3



Certain of the mathematical formulae appearing in the printed specification were submitted in formal form after the date of filing.
This print embodies corrections made under Section 117(1) of the Patents Act 1977.

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FIG. 1

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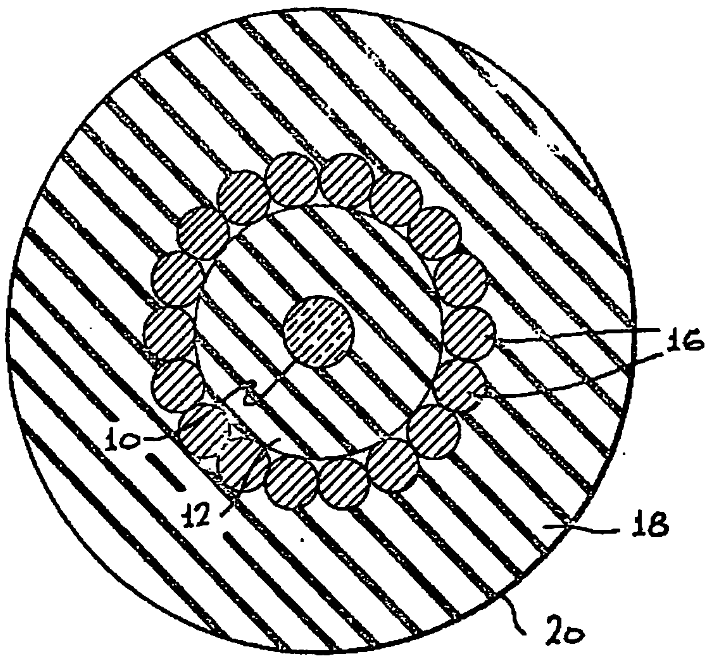

FIG. 2

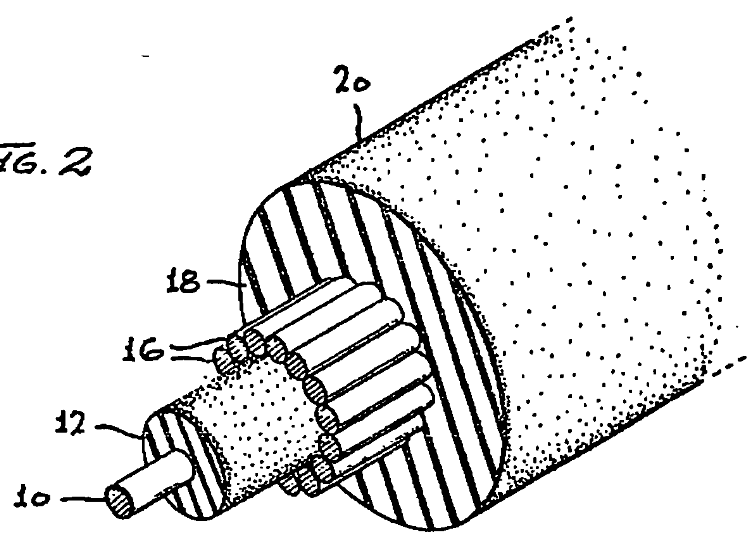

FIG. 3

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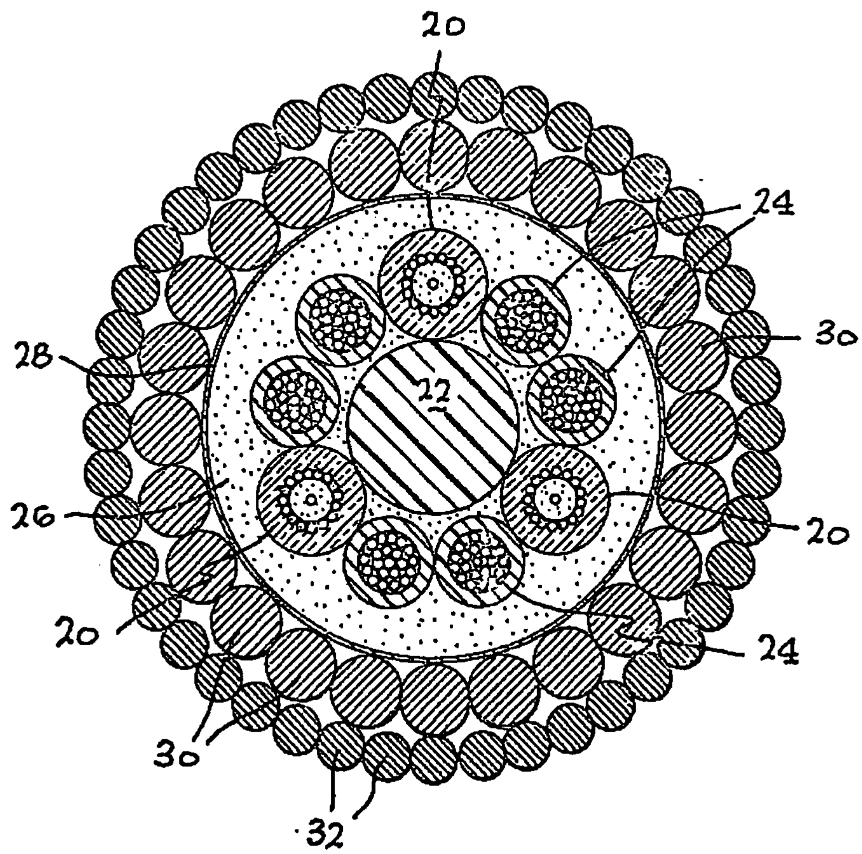

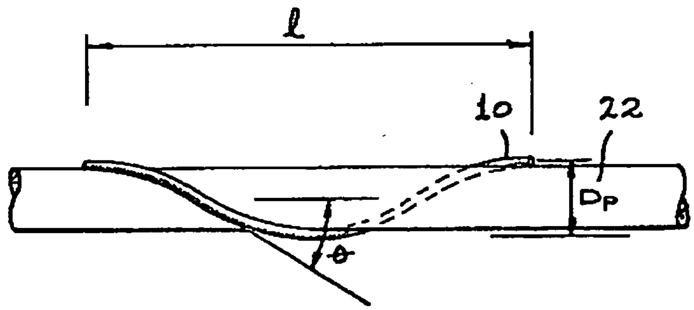

FIG. 5

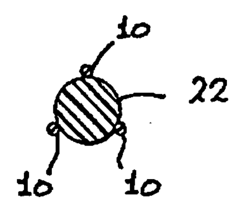

FIG. 5A

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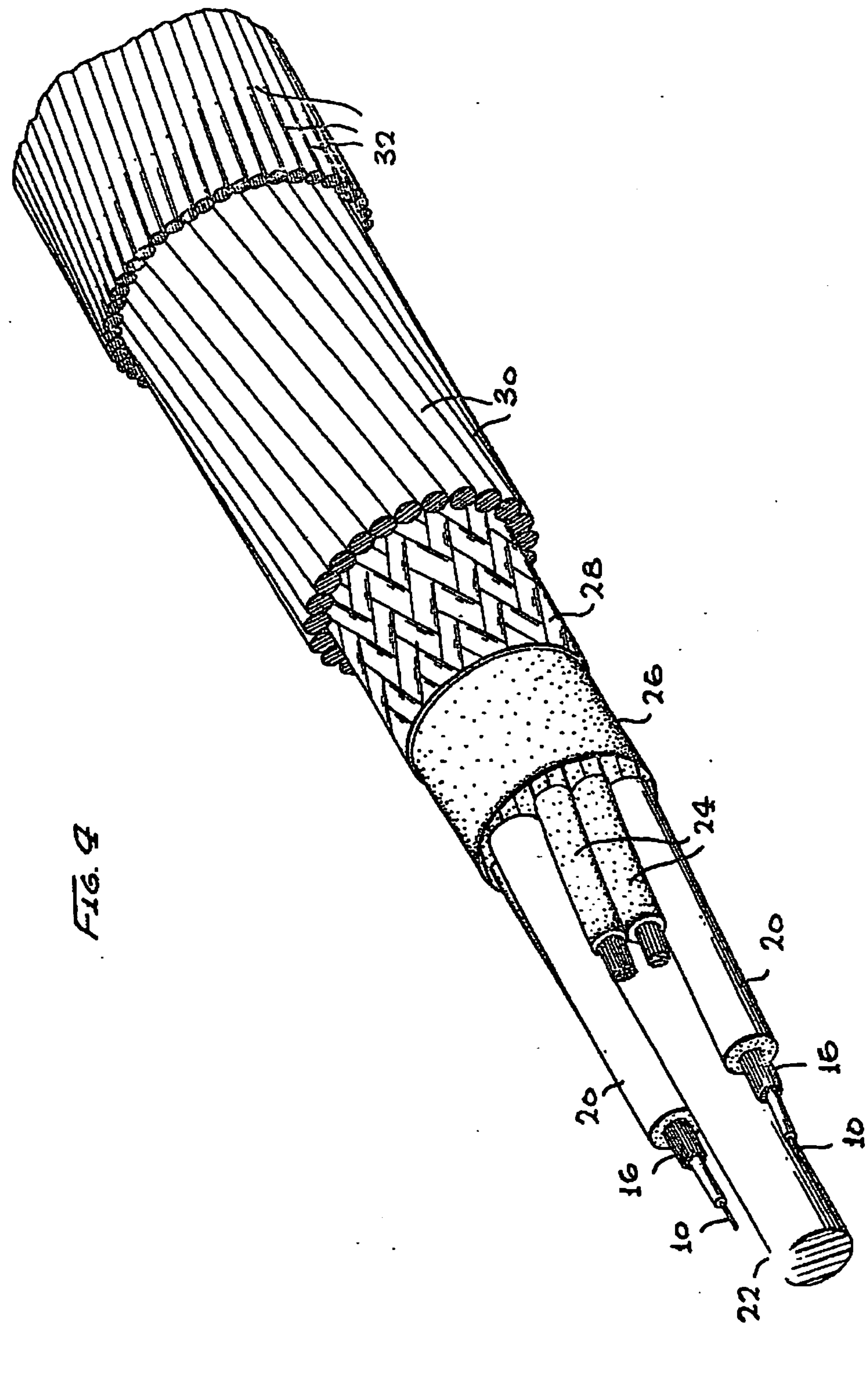

FIG. 4

SPECIFICATION

An Optical Fiber Conductor and Optical Fiber Cable Incorporating Such Conductors

The invention relates to a reinforced optical fiber conductor and to an optical fiber cable incorporating such conductors.

Despite certain recognized structural weaknesses, fiber optic conductors remain attractive for many applications because they are capable of transferring more information in a given period of time than can conventional metal conducting wires. In addition to handling higher data rates, a fiber optic communication system is essentially free from radiation or electromagnetic interference into nearby electrical systems. Where long lengths of cable are used, optical fiber cable is considerably lighter in weight than conventional electrical conductors. When optical fiber conductors are incorporated into a cable they may be subjected, in addition to tensile loads, to lateral loads and to surface stress resulting from their being wound on a reel spool or sheave. When such conductors are to be repeatedly reeled over drums or sheaves, they must be protected from rough surfaces on such sheaves or drums which can result in forming small radius microbends in the fiber which cause attenuation of the signal.

To inhibit deterioration from growth of surface cracks, etc. such conditioners, which are typically of silicate glass, are coated or "buffered" with a thin layer of plastic material.

The microbend problem is dealt with extensively in U.S. Patent No. 4,000,936 in the name of D. C. Gloge and assigned to Bell Telephone Laboratories, Inc. In the Gloge patent a number of configurations are described for encasing the small optical fibers in protective jackets, some of which are quite thick and soft, for minimizing external forces on the fiber and thus minimizing distortion losses.

While the soft protective jacket described by Gloge deals with the microbend problem for many applications, it does not solve the structural problems of fiber optic conductor applications involving substantial tensile stress from axial loads, further stress from being cycled hundreds or thousands of times over sheaves and reels, and the need for minimum weight. These stress problems may be further compounded by placing a plurality of such fiber optic cables within a congested cable subjected to both tensile stress and repeated cycling over sheaves and reels.

It is an object of the present invention to deal with the special microbend problems resulting from repeated reeling of the optical fibers over reels and sheaves and to provide means which will carry the largest part or almost all of the tensile stress.

T this end the invention proposes a reinforced optical fiber conductor characterized in that it comprises a buffered silicate glass fiber, a compliant jacket of insulating material of thickness substantially greater than the diameter of said fiber surrounding said fiber, a reinforcing layer of side-by-side small diameter hard drawn wires concentrically arranged outsid of said compliant jacket, and a plastic jacket of substantial thickness retaining said layer of wires in their cylindrical arrangement.

The invention also proposes an optical fiber cable including a centrally disposed plastic rod, a plurality of conductors wrapped around said rod at a small angle with respect to the direction of said rod, a flexible insulating jacket surrounding said conductors and filling the spaces between said conductors and strength members wrapped around said insulating jacket, characterized in that at least one of said conductors comprises a buffered silicate glass fiber coated with plastic having a compliant jacket of insulating material of thickness substantially greater than the diameter of said fiber surrounding said fiber, a reinforcing layer of side-by-side small diameter hard drawn wires concentrically arranged outside of said compliant jacket and a plastic insulating jacket of substantial thickness retaining said wires, and said strength members include an inner layer of generally parallel strands, wound at a small angle with respect to said rod in a first direction and an outer layer of generally parallel strands wound at a small angle with respect to said rod in a second direction.

The angle chosen is, in each case, about fifteen degrees with respect to the angle of the centrally disposed plastic rod, with the inner layer laid in a left hand helix angle and the outer layer in a right hand helix angle, the opposite directions chosen such that when the cable is under load it is essentially torque-balanced and will not have a tendency either to spin a transducer attached to the deep end of the cable or to snarl when unloaded as the ocean floor is reached.

The invention will now be described with reference to the accompanying drawings wherein:

Figure 1 is a cross-sectional view of a single jacketed and buffered optical fiber conductor with strength members according to the invention.

Figure 2 is a perspective view of the optical fiber conductor of Figure 1 shown partially cut away.

Figure 3 is a cross-sectional view of cable made according to the invention.

Figure 4 is a perspective view, with various parts cut away, of the cable of Figure 3.

Figure 5 is a plan view of a typical optical fiber wound on a plastic rod.

Figure 5 is an end view of the organization shown in Figure 5.

Referring now to Figure 1, a buffered optical fiber conductor is shown at numeral 10 surrounded by a compliant jacket 12 which may be of synthetic rubber. The optical fiber conductor 10 may be about 0.125 mm diameter with the compliant jacket 12 being approximately 0.185 mm thick. Surrounding jacket 12 is a layer of steel wires 16, ach of which may be of 0.100 mm diameter. These wires are laid parallel to or spiralled at a shallow angle, such as fifteen degrees, with respect to conductor 10 and are, in

turn, covered and secured in position by means of an outer jacket 18 of synthetic rubber or Hydrel of such thickness as to bring th outside diameter of the jacketed conductor 20 to 1,25 mm.

Figure 2 shows the conductor of Figure 1 in a perspective view with portions cut away to more clearly show the relationship of the parts. The outer jacket 18 is cut back to expose the sheath of parallel fine wires 16 which extend forward of jacket 18. Extending forward of the sheath of wires 16 is a short length of the inside jacket 12 which directly surrounds the optical fiber 10. In this view it is clear that the individual wires of the sheath 16 are adjacent each other and all run parallel to the optical fiber 10. For some applications it might be advantageous to apply the wires of sheath 16 in a slight spiral, probably not more than about fifteen degrees with respect to optical fiber 10. This arrangement will provide somewhat lower elastic modulus but with slightly more flexibility than the straight wire sheath described above.

Three of the conductors thus far described are incorporated in a cable designed for use in deep water which must support a transducer of substantial weight and withstand repeated reeling over a sheave and on and off a drum. A cross-sectional view of this cable appears in Figure 3. At the center is a monofilament plastic rod 22 of 1.75 mm diameter around which are wrapped nine conductors, three of which are the jacketed fiber optic conductors 20 arranged 120 degrees apart with six other conductors 24 which are stranded copper wire conductors of 0.625 mm diameter insulated with polypropylene of 0.175 mm thickness to give conductors 24 a diameter of 0.95 mm. All of conductors 20 and 24 are wrapped around the center plastic rod 22 at a fifteen degree left hand helix angle. Surrounding the conductors 20 and 24 is an extruded layer 26 of polyurethane or equivalent insulation, preferably of about 80 A Shore hardness, which penetrates between the conductors to fill any potential voids between and under the conductors, which layer is of such thickness to bring its external diameter to approximately 5 mm. A bedding braid 28 of Dacron or equivalent synthetic fiber is wrapped around the extruded layer 26. Strength members are provided by an inner layer 30 of 24 wires of 0.75 mm diameter laid in a fifteen degree left helix and an outer layer 32 of 44 wires of 0.5 mm diameter laid in a fifteen degree right helix. By having the two strength member layers 30 and 32 wound on the cable in opposite directions, the torque forces tending to twist the cable when under tension are balanced, minimizing the tendency of the cable to twist and snarl or to spin a transducer suspended at th nd of the cable.

Figure 4 is a perspective view of th cabl shown in cross-section in Figure 3. Successive layers are shown cut away to clarify the reader's understanding of the structure. In this figure th monifilament plastic rod 22 is shown along the center line with the jacketed fiber optical conductors 20 arranged 120 degrees apart and wrapped around the rod 22 at a shallow angle which in this case is fifteen degrees with reference to the center line of rod 22. Each of the jacketed conductors 20 is shown with a portion of jacket 18 cut away to show the single layer 16 of steel wires which, along with jackets 12 and 18, serves to protect the fiber optic conductor 10 from microbends and from being exposed to excessive tensile loads as discussed above. Spaced between each of the jacketed conductors 20 are two of the insulated stranded copper conductors 24 which are, of course, also laid around the center rod 22 at a fifteen degree left helix. The extruded polypropylene layer 26 is shown encasing the conductors 20 and 24 and, in turn, is covered and secured in position with the textile bedding braid 28. The inner strength member 30 consisting of 24 0.75 mm diameter steel wires is shown laid on the braid 28 at a fifteen degree left hand helix. Outer strength member 32 containing 44 steel wires of 0.5 mm diameter is wrapped on the outside of layer 30 in a fifteen degree right hand angle.

Each of the three optical fibers 10 thus buffered and strengthened is laid into a discrete helix angle around the center plastic rod 22. This angle is selected to prevent overstressing the silicate glass fiber 10 according to the formula:

$$R = \frac{D_p}{2(\sin \theta)^2}.$$

where R is the minimum allowable fiber radius, D_p is pitch diameter of the helix, and θ is helix angle as shown in Figure 5. In the case of this invention a 25 mm radius results in an optical fiber flexural stress of 1.750 kg/cm² an acceptable level to resist fatigue (repeated reeling) failure. The above is discussed in somewhat greater detail in "Stress Analysis of Wire Rope in Tension and Torsion" by Dr. Charles W. Bert and Robert A. Stein, from Wire and Wire Products, May 1962.

Figure 5a is a sectional view taken through Figure 5 but modified to show that there are in fact three optical fibers wrapped around the center rod 22.

Typical undersea cables are loaded in tension to produce one per cent elongation. Since all elements of the cable endure the same elongation, the tension on each element is expressed as:

$$T = E \cdot A \cdot \varepsilon$$

where E is the modulus of elasticity of the material of each element as processed in the cable configuration, A is the cross-sectional area of the component material, and ε is unit elongation as taught in U.S. Patent No. 4,093,342.

The tensile strength of state-of-the-art silicate glass fibers used as optical conductors is 14000 kg/cm² when tested in 1 km lengths. Practice has

shown that fatigue stress levels, including flexural and tensile, must be no greater than three-eighths (5250 kg/cm²) of this level for adequate stress cycling reliability. Bend radius of a 0.125 mm diameter optical fiber is limited, therefore, to no less than 25 mm since its modulus of elasticity is 7.10^5 kg/cm² resulting in a flexural stress of 1750 kg/cm² given by:

$$S = E \cdot \left(\frac{r}{R}\right)$$

where S is unit flexural stress, r is the fiber radius, and R is the bend radius of the fiber. Further, tensile stress must be limited to produce a combined maximum of 5250 kg/cm² as above. Using the above flexural stress formula, wire stress is 16800 kg/cm² at a minimum bend radius of 25 mm, within the stress limitations of the metallic wire material.

Structural enhancement for the optical fiber in tension is gained through the relationship of the elastic moduli of the silicate glass and the metallic wire, which in this case is a ratio of one to two. It can be seen that, with common elongations, the glass will be stressed to one half of the metal. Since the metallic wires are normally stressed to a maximum of 7000 kg/cm² for cycling reliability purposes (which is a four-to-one safety factor), the glass fiber is stressed in tension to 3500 kg/cm². Adding to this tensile mode its flexural mode (1750 kg/cm²), as described above, a maximum tension of 5250 kg/cm² is applied, which is within reliability limits as described in the foregoing rationale.

Fatigue stress levels are characteristically determined from practical experience and are in essence arbitrarily set. Although cycle fatigue curves are available for pure (straight bar) materials, variables are introduced by the cabling process. Metallic wires of the nature described in the present invention possess breaking stresses of 25000 to 35000 kg/cm² and elastic moduli of 21×10^5. Where reliability must be such that the conductor will withstand at least 1,000 payout and retrieve cycles, a four or five to one safety factor is known to be adequate.

The plastic jacket, though low in elastic modulus (i.e., 350 kg/cm²) relative to other materials of the cabled optical fiber, is structurally capable of retaining the concentric wires in their cylindrical form when subjected to both microbends and bends over sheaves and reels. The selection of plastic Shore hardness is made based on the above compatibility. The described construction provides good flexural fatigue resistance which enhances reliability during repeated load cycling operation. Wire consolidation provided by th jacket assures complete retention of th metallic cylinder (as a structure form). Thus, when it is bent on a 25 mm radius, the structure bends as a beam with neutral axis at the optical fiber center, and therefore the outer elements (wires) which are already in tension receive an additional flexural tension load. The flexural stress on the inner lements is in compression which effectively substracts from the normal tension load. It is a significant feature of this invention that the metallic structural members will accept compressive loads in flexure as opposed to structural members of aromatic polyamides, structural glass fibers, etc., which possess low compressive load capacity, particularly in the fatigue stress environment.

Where the cable described above, which in the case of applicant's particular design has an outside diameter of 7.5 mm, is not sufficiently strong to carry a particular tensile load, it is possible to add further strength by adding an additional armor layer, taking care that the angle and directions of the armor layers are such as to retain the torque balancing feature. Or the size of the wires in the two-layer arrangement may be increased. For use at very great depths where the cable must be of such length that the weight of the steel armor becomes excessive, it is possible to substitute armor layers of aramid fiber (Kevlar) for the steel wire layers. Depending on forces and dimensions of a particular installation, this may result in some loss in the numbers of reeling cycles which the cable can withstand because of the relative weakness of aramid fibers in compression, as described above.

Claims

1. A reinforced optical fiber conductor characterized in that it comprises a buffered silicate glass fiber, a compliant jacket of insulating material of thickness substantially greater than the diameter of said fiber surrounding said fiber, a reinforcing layer of side-by-side small diameter hard drawn wires concentrically arranged outside of said compliant jacket, and a plastic jacket of substantial thickness retaining said layers of wires in their cylindrical arrangement.

2. A reinforced optical fiber conductor according to claim 1, characterized in that said plastic jacket is of greater thickness than said compliant jacket.

3. A reinforced optical fiber conductor according to claim 1, characterized in that the hardness of said plastic jacket is selected such that it retains said layer of wires in position when said conductor is bent over sheaves and reels.

4. A reinforced optical fiber conductor according to claim 1, characterized in that said plastic jacket retains said layer of wires in position such that the layer of wires functions as a metallic cylinder and when said conductor is subjected to bending, it bends as a beam with its neutral axis at the center of said optical fiber.

5. A reinforced optical fiber conductor according to claim 1, characterized in that said layer of wires is arranged parallel to said buffered glass fiber.

6. A reinforced optical fiber conductor according to claim 1, characterized in that said buffered glass fiber is approximately 0.125 mm diameter, said compliant jacket is approximately 0.185 mm thick, the wires in said layer of steel wires are 0.1 mm diameter, and said plastic

jacket is of such thickness as to increase the outer diameter of said conductor to 1.25 mm.

7. A reinforced optical fiber conductor according to claim 1, characterized in that said buffered glass fiber and said layer of wires are dimensioned such that when said layer of wires is stressed to its maximum safe tensile load in terms of kilograms per square centimetre the tensile load on said buffered glass fiber in terms of kilograms per square centimetre does not exceed approximately one-third of that on said layer of wires.

8. A reinforced optical fiber conductor according to claim 1, characterized in that said plastic jacket is extruded over said wires such that it also fills the spaces between and below the individual said wires to assure retention of said wires.

9. An optical fiber cable including a centrally disposed plastic rod, a plurality of conductors wrapped around said rod at a small angle with respect to the direction of said rod, a flexible insulating jacket surrounding said conductors and filling the spaces between said conductors and strength members wrapped around said insulating jacket: characterized in that at least one of said conductors comprises a buffered silicate glass fiber coated with plastic having a compliant jacket of insulating material of thickness substantially greater than the diameter of said fiber surrounding said fiber, a reinforcing layer of side-by-side small diameter hard drawn wires concentrically arranged outside of said compliant jacket and a plastic insulating jacket of substantial thickness retaining said wires; and said strength members include an inner layer of generally parallel strands, wound at a small angle with respect to said rod in a first direction and an outer layer of generally parallel strands wound at a small angle with respect to said rod in a second direction.

10. An optical fiber cable according to claim 9, characterized in that a braided layer of textile material covers said flexible insulating jacket and underlies said strength members.

11. An optical fiber cable according to claim 9, characterized in that said strength members include first and second layers of steel armor wires.

12. An optical fiber cable according to claim 9, characterized in that said cable includes at least three of said glass fiber conductors.

13. An optical fiber cable according to claim 9, characterized in that said cable includes at least one conductor with conventional metal conducting wires.

14. An optical fiber cable according to claim 12 characterized in that said cable includes a pair of conventional metal conducting wires positioned between each of said glass fiber conductors.

15. An optical fiber cable according to claim 9, characterized in that said strength members are of aramid fibers.

16. An optical fiber cable according to claim 9, characterized in that said reinforcing layer of side-by-side small diameter hand drawn wires are wound on said compliant jacket of insulating material in a shallow angle with respect to the direction of said centrally disposed plastic rod.

17. An optical fiber cable according to Claim 10, characterized in that said strength members include first and second layers of steel armor wires and in that said cable includes at least one conductor with conventional metal conducting wire.

18. An optical fibre cable substantially as described and as shown in the accompanying drawings.

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